



## Invasive Marine and Estuarine Animals of the South Atlantic and Puerto Rico

by Gary L. Ray

**PURPOSE:** New species of estuarine and marine animals are inadvertently or intentionally introduced into the waters of the United States every year (Figure 1). Various referred to as introduced, nonindigenous (NIS), alien, nonnative, or exotic species, most pose little or no threat; however, a few have the potential to disrupt local ecosystems, fisheries, and human infrastructure. Such invasions directly impact the mission of the U.S. Army Corps of Engineers (USACE) through its responsibilities for construction and maintenance of harbors, ports, and waterways; erosion control; management of water resources; and wetland and coastal habitat restoration. The general biology and ecology of invasive estuarine and marine animals have been described in previous reports (Carlton 2001, Ray 2005). This report is part of a series describing the biology and ecology of known invasive estuarine and marine animals in the major geographic regions of the United States. Invasive animals of the South Atlantic region including Puerto Rico are described and examples of species posing a specific threat to USACE activities are identified.

**BACKGROUND:** Invasive species are officially defined as “alien species whose introduction does or is likely to cause economic or environmental harm to human health” (Executive Order 13112, Federal Register (1999)). Any species removed from its native range has the potential to become invasive. Within a species’ normal range, predation, disease, parasites, competition, and other natural controls act to keep population levels in check (Torchin et al. 2003, Wolfe 2002). Once released from these controls, species abundances have the potential to reach levels that interfere with or displace local fauna. Such effects may occur immediately, after some period of delay, or may never be realized at all depending on the characteristics of the individual species and the conditions into which it is introduced.



Figure 1. Example of a nonindigenous species, the Green Porcelain Crab, *Petrolisthes armatus* (image courtesy of Southeast Regional Taxonomic Center)

Lists of estuarine and marine nonindigenous species are often dominated by mollusks, crustaceans, and polychaete worms; however, this may reflect their ease of identification and detection rather than the degree to which they are representative. Ultimately, it is an issue of an organism’s biological characteristics (e.g., reproductive capacity, growth rate, etc.) and not its taxonomic affinities that determine if it becomes invasive. Successful invaders tend to be abundant over a large range in their

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>SEP 2005</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>Invasive Marine and Estuarine Animals of the South Atlantic and Puerto Rico</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>U.S. Army Engineer Research and Development Center Vicksburg, MS</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>The original document contains color images.</b>					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>UU</b>	18. NUMBER OF PAGES <b>14</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

native region, have broad feeding and habitat preferences, wide physiological tolerances, short generation times, and high genetic variability (Erlich 1989, Williams and Meffe 1999). Despite the fact that we can identify these characteristics, predicting which species pose the greatest threat remains problematic. While many species possess these characters, most are not obvious in their native range, and the opportunities for introduction and subsequent likelihood of survival are difficult to assess. The situation is further complicated by difficulty in distinguishing invaders from species with naturally wide distributions and those that are cryptogenic; that is, species whose original distributions are uncertain.

Predicting which habitats are likely to be invaded is much simpler. Invaded habitats tend to have low natural diversity, relatively simple (low-connectance) food webs, and a history of recent natural or anthropogenic disturbance (Williams and Meffe 1999). Estuaries and sheltered coastal areas are among the most invaded habitats, presumably due to the fact that they are naturally disturbed, low-diversity systems, and are historically centers of anthropogenic disturbance associated with navigation, industrial development, and urbanization.

Species can be introduced by a variety of different mechanisms; however, most estuarine and marine species introductions are associated with shipping (Ruiz et al. 2000). Species capable of attaching to hard surfaces may be transported on ship hulls, navigational buoys, floatation devices, anchors, chains, ropes, and flotsam or jetsam (Carlton 2001). During the heyday of wooden-hulled ships, wood borers (e.g., shipworms) and species associated with “dry” ballast such as stones, rock, sand, or other materials were frequently introduced (Carlton and Hodder 1995). Presently, the largest single source of shipping-related introductions is ballast water (Carlton 1985, Lavoie et al. 1999). Ballast water is taken onboard vessels for a variety of purposes related to ship maneuverability and control (Carlton et al. 1995). Animals suspended in the water column or present in bottom sediments are taken in and then introduced to a new location when the ballast is pumped out.

Recently, concerns have also been raised regarding introductions of fish, invertebrates, and “live” rock from the aquarium trade (Padilla and Williams 2004, Weigle et al. 2005). The lionfish *Pterois volitans* may have been introduced when a private aquarium was demolished in the Miami area during Hurricane Andrew in 1992 (Hare and Whitfield 2003). Other introductions may result from accidental release of animals, inappropriate disposal of packing material by restaurants serving live seafood, and by the live bait industry. Many species have been deliberately introduced to develop new fisheries. For example, the Atlantic striped bass (*Morone saxatilis*) has been introduced both outside its normal geographic range and in non-native habitats (e.g., reservoirs) in much of the United States.

**METHODS:** As indicated in the official definition, invasive species are nonindigenous or alien to the region in which they are found. This does not mean that all NIS are invasive, but rather that invasives constitute a subset of NIS. For the purposes of this report, the South Atlantic region is defined as the area from Chesapeake Bay to the Florida Keys including the island of Puerto Rico. In order to create a list of known invasive species within this region, NISBase, a national database of NIS listings maintained by the Smithsonian Institution ([www.nisbase.org/nisbase/index.jsp](http://www.nisbase.org/nisbase/index.jsp)) was queried. Part of the National Exotic Marine and Estuarine Species Information System (NEMESIS), this database permits simultaneous searches of multiple NIS listings. Searches return up to 300 species and include links to individual species’ fact sheets and collection data. Queries were

performed by state and included searches of the U.S. Geological Survey's Nuisance Aquatic Species (NAS) database (<http://nas.er.usgs.gov/>), the Chesapeake Bay Exotic Marine and Estuarine Species Information System database, and the Nonindigenous Species in the Gulf of Mexico database (<http://nis.gsmfc.org/>). The resulting lists were amended as necessary after comparison with individual state NIS listings and other reports (Table 1) and then edited to include only estuarine and marine species (Appendix A). Cryptogenic species were not included in this list. Only species known to be invasive or possessing the potential to become invasive are discussed.

**Table 1**  
**State NIS Listings and Other Sources Utilized in This Report**

Benson et al. 2001
Nature Conservancy 2004
U.S. Environmental Protection Agency 2000
University of Georgia 2002
United States Geological Survey 2003

**RESULTS:** A total of 118 nonindigenous estuarine and marine animal species were encountered in listings for the South Atlantic region (Table 2). Fishes and molluscs dominated these lists, with 27 species apiece. At least 11 of the fish species represent deliberate introductions associated with sport fisheries or mariculture operations and include shad and herrings (*Alosa aestivalis*, *A. pseudoharengus*, *A. sapidissima*, *Dorosoma cepedianum*, and *D. petenense*), salmon (*Onchorhynchus* spp. and *Salmo salar*), cod (*Gadus morhua*), and striped bass (*Morone saxatilis*). An additional 15 fish species represent unintentional releases from aquaria including six species of

**Table 2**  
**Summary Results for Numbers of South Atlantic NIS by State**

Species	VA	NC	SC	GA	FL	PR	Total for Region
Protozoans	2	1	1	1	1		2
Scyphozoans	3		1		2	1	5
Anthozoans	2				2		3
Oligochaetes	1						1
Polychaetes	5				3		7
Bivalves	8	1		1	7		13
Gastropods	8				4		10
Nudibranchs	2				2		4
Copepods	2	1	1		1		2
Barnacles	2	1	1		3		4
Amphipods	6				1		7
Isopods	2	1	2		3		4
Tanaids					1		1
Mysids	1						1
Crabs	2	2	2	2	5		8
Shrimp			3	1	4		4
Insects	2						2
Bryozoans	1				2		3
Entoprocts	2						2
Tunicates	9				2		9
Fish	10	5	2	8	18	1	27
Total	70	12	13	13	61	2	118

angelfish (*Pomacanthus* sp.), five species of tang (*Zebrasoma* spp.), spotted scat (*Scatophagus argus*), blackbelly triggerfish (*Rhinecanthus verrucosus*), humpback grouper (*Cromileptes altivelis*), swamp eel, (*Monopterus albus*) and lionfish (*Pterois volitans*). Only the lionfish and swamp eel have been recognized as species of concern at this time.

The Pacific oyster, *Crassostrea gigas*, is another introduced species planted to replace declining stocks of native oysters (*C. virginica*) in Chesapeake Bay. There is presently considerable debate over the introduction of a second species, the Suminoe oyster, *C. ariakensis* (<http://www.chesapeakebay.net/nonnativeoyster.htm>). Several species have been unintentionally introduced during shellfish stocking programs including the oyster-disease-causing protozoans *Haplosporidium nelsoni* and *Perkinsus marinus* and the Japanese oyster drill *Eupleura sulcidentata*. *Perkinsus* (more commonly called Dermo) was first detected in Louisiana in the 1950's and has since spread throughout the Gulf of Mexico and up the east coast as far north as New Jersey.

Geographical distribution of NIS varies widely among states. Florida and Virginia have the greatest number of reported NIS, probably reflecting the extent of coastline, intensity of human influence (e.g., shipping and industrialization), and the existence of NIS monitoring efforts in these states. Most aquatic NIS reported from Puerto Rico are freshwater species and nearly all represent deliberate introductions (Benson et al. 2001). The low number of estuarine and marine NIS presently reported for Puerto Rico may reflect the difficulty in determining the origin of many species or differences in the intensity of monitoring efforts.

**DISCUSSION:** Species most commonly identified as invasive or listed as of concern in the South Atlantic include Australian spotted jellyfish (*Phylloriza punctata*), Veined rapa whelk (*Rapana venosa*), Green-lipped mussel (*Perna viridis*), Brown mussel (*Perna perna*), shipworms, Japanese shore crab (*Hemigrapsus sanguineus*), Green porcelain crab (*Petrolisthes armatus*), Lionfish (*Pterois volitans*), and Asian swamp eel (*Monopterus albus*). Of these species, the biology and ecology of all but shipworms and the swamp eel have been previously described (Ray 2005). Basic information on the swamp eel can be found at the Aquatic Nuisance Species Research Program website ([http://el.erd.usace.army.mil/ansrp/monopterus\\_albus.htm](http://el.erd.usace.army.mil/ansrp/monopterus_albus.htm)). These results are briefly summarized below.

## Potential Threats to Infrastructure

**Mussels:** The Asian green mussel *Perna viridis*, a native of the tropical Indo-Pacific, has been collected from Tampa Bay to Charlotte Harbor, Florida as well as Kingston Harbor, Jamaica (Buddo et al. 2003). It has planktonic larvae capable of settling on almost any hard surface. The initial discovery of this species in Tampa Bay was due largely to the fact it was clogging water intake pipes at local power plants (Gulf States Marine Commission 2003). It fouls navigation buoys and ship hulls, interferes with shellfish culture, and displaces local fauna. This species could also potentially harbor algal species that produce toxic shellfish poisoning (Buddo et al. 2003). A close relative, the brown mussel (*P. perna*) is also a potential fouling threat. Native to South Africa, it has successfully invaded South America from Uruguay to the Caribbean and is now distributed from Freeport, Texas to Veracruz, Mexico (Hicks and Tunnel 1993, 1995, Hicks et al. 2001). Slightly smaller than its congener, the brown mussel shares most of its biological characteristics. Its planktonic larvae reside in the water column for up to three weeks potentially allowing it to invade much of the Gulf of

Mexico and the Florida Keys. Like the green-lipped mussel, it can settle on almost any hard surface and has been reported from jetties, navigational buoys, oil platforms, and natural hard bottom substrates (Hicks and Tunnell 1995).

An additional 26 NIS species (22 percent) can also be classified as fouling species. Most likely introduced on ships' hulls or in ballast water, they include three anemones, four barnacles, three bryozoans, two entoprocts, nine tunicates, two polychaetes, and three bivalves (Appendix A). None of these species have been listed as species of immediate concern.

**Molluscs:** Four species of wood-boring bivalve molluscs, commonly called shipworms, are present in the South Atlantic. The native range of *Teredo bartschi* extends from Texas to South Carolina. It is now found in Chesapeake Bay and occasionally as far north as New Jersey. The native ranges of two other *Teredo* species, *T. furcifera* and *T. navalis*, are uncertain, but both now have cosmopolitan distributions. *Lyrodus medilobatus*, an Indo-Pacific species detected at Cape Canaveral in 1995, was probably introduced on a fouled ship hull (USGS 2005). Shipworms are generally tolerant of a wide range of salinities, temperatures, flow conditions, and oxygen concentrations. These filter-feeding molluscs are dispersed by planktonic larvae. The larvae settle and construct extensive burrow systems on any wooden structures (e.g., boat hulls, marinas, docks, and pilings). Cohen and Carlton (1995) report that shipworms caused \$615 million in damage in San Francisco Bay during a 1920's outbreak. Likewise, severe damage was reported in Barnegat Bay, New Jersey and Long Island Sound, New York following outbreaks of *T. bartschi* associated with increased water temperatures and salinities in power station effluents (Hoagland 1983). Effective control of these pests can be accomplished by chemical treatment (e.g., creosote) of wood or use of alternative materials (Highley 1999).

## Potential Threats to Habitat Restoration

**Veined rapa whelk:** *Rapana venosa*, the Veined rapa whelk, a native of the Sea of Japan, was first detected in Chesapeake Bay in 1998 (Mann and Harding 2000). Already known as an invasive species in the Black, Adriatic, and Aegean Seas, it is thought to have entered the United States via ballast water. It prefers hard sandy bottoms with salinities of 18-28 ppt and can reach a total length of 150 mm. While juveniles feed on barnacles, mussels, and newly settled and very young oysters, adults feed heavily on softshell clams (*Mya arenaria*) and hard clams (*Mercenaria mercenaria*). The rapa whelk has the potential to affect restoration of shellfish habitat in Chesapeake Bay and elsewhere. Distribution of this species is presently limited to portions of Chesapeake Bay, but it will likely spread north to Cape Cod and south to Cape Hatteras (Mann and Harding 2003).

**Australian spotted jellyfish:** Australian spotted jellyfish *Phylloriza punctata* is presently found in abundance only in the northern Gulf of Mexico, but has been reported as far afield as Brevard County, Florida. This large jellyfish (average adult bell width is 35 cm) can be found in swarms of up to 500,000 in a 150-km<sup>2</sup> area. Feeding intensively on zooplankton and fish larvae, these jellyfish represent a potential threat to fisheries and fisheries restoration operations.

**Green porcelain crab:** The green porcelain crab (*Petrolisthes armatus*) (Figure 1) is a South American and Caribbean species now distributed as far north as Georgia and South Carolina. Found in rocky intertidal and tidal creek oyster bar habitats, it is presently undergoing large changes in both



distribution and abundance, reaching densities as high as 10,000/m<sup>2</sup> in South Carolina salt marshes (Lohrer 2001). It is unclear whether this represents a natural range expansion or an inadvertent introduction. Hartman et al. (2001) and Hollebone and Hay (2003) suggest that high abundances of *P. armatus* provide an alternative prey for predators of xanthid crabs. Xanthids are important predators of newly settled oysters; therefore, the increase in green porcelain crab indirectly results in a negative impact on oyster populations. Obviously, such an effect has important implications for oyster habitat restoration efforts in the South Atlantic.

**Asian swamp eel:** The Asian swamp eel *Monopterus albus* is not a true eel, but a member of the fish family Synbranchidae. Nocturnal in habit, it burrows as deep as 1.5 m in the bottoms of ponds, streams, rivers, and other freshwater habitats. It can also tolerate both saline and brackish waters. The swamp eel feeds on fishes, worms, crustaceans, and other aquatic species. Marketed as an aquarium species, it may have been introduced accidentally by aquarium release. It is presently found in drainages in southern Florida as well as the Tampa Bay region. It may interfere with USACE operations by displacing native species and its extensive burrow systems may contribute to accelerated drying of shallow water bodies. For more information on this species, see either the ANSRP website (listed above) or the Gulf States Marine Fisheries Commission NIS fact sheet (<http://nis.gsmfc.org>).

**Japanese shore crab:** The Japanese shore crab *Hemigrapsus sanguineus*, a native of the western Pacific Ocean, is characteristically found in low intertidal and subtidal zones with rock or cobble substrates. First detected in New Jersey in 1988 (McDermott 1991), it has since spread north into southern New England (Lohrer and Whitlatch 1997) and south into Chesapeake Bay. It has quickly become one of the most abundant crabs in the rocky intertidal zone, displacing native xanthid crabs and even the invasive green crab from areas where their distributions overlap (Lohrer and Whitlatch 1997, Jensen et al. 2002). It has an extended breeding season and tolerates salinities as low as 15 ppt as larvae (Epifaunio et al. 1998). Adults appear to prefer salinities of 20 ppt or higher. The Japanese shore crab has broad food preferences including macroalgae, snails, mussels, and barnacles (Lohrer and Whitlatch 1997, Bourdeau and O'Connor 1999, Percival and Wilson 2001). While it seems doubtful this species will directly interfere with USACE operations, the issue of incidentally contributing to its spread may arise in situations where riprap or other coarse materials are placed in the intertidal zone.

**Wood-boring isopods:** Two wood-boring isopods are present in the South Atlantic (*Sphaeromateobius* and *S. walkeri*), both of which may endanger habitat restoration efforts. The first of these was probably introduced on the hulls of wooden ships. Now found from Brazil to South Carolina and from Liberia to the Congo (Carlton and Ruckelshaus 1997), it burrows into hard substrates including hard-packed sand, and decaying or living wood. There is considerable concern over its potential impact on restoration of mangrove habitat. The isopod burrows into the prop roots of red mangrove (*Rhizophora mangle*), weakening and ultimately destroying them (Rehm and Humm 1973). This not only damages the individual mangrove plant, but leads to undercutting and erosion of exposed sediments. Impact of the introduction of the southwestern Pacific *S. walkeri* is unknown (Fuller 2005).

**Potential Threats to Human Health.** The lionfish *Pterois volitans* (Figure 2), a native of the Indian Ocean and western Pacific coral reefs, is a favorite aquarium fish because of its colorful appearance. Lionfish bear poisonous dorsal, anal, and pelvic spines. The toxin is painful, but is generally not fatal. It was first noticed in Florida waters in 1994 and may have been introduced when a private aquarium was demolished in the Miami area during Hurricane Andrew in 1992 (Hare and Whitfield 2003). Associated with hard bottoms, coral reefs, and artificial substrates from 26 to 79 m deep, it is generally found on ledges and crevices from Florida to Cape Hatteras, North Carolina. It has also been reported in Puerto Rico. Lionfish feed mostly upon small fish, crabs, and shrimp; however, their impact on local ecosystems has not been assessed.



Figure 2. The Lionfish, *Pterois volitans* (image courtesy of Florida Fish and Wildlife Conservation Commission)

### Potential Future Threats

**Chinese mitten crab and Asian date mussel:** Although yet not reported from the South Atlantic, two species are of particular concern in this region. These include the Chinese mitten crab *Eriocheir sinensis* and the Asian date mussel *Musculista senhousia*. The mitten crab first appeared as an invasive species in Germany during the early 1900's and has since spread through most of Europe (Clark et al. 1998) and is now in the United States. It is reported from Lake Erie, San Francisco Bay, the Columbia River, and Mississippi Sound. The crabs are catadromous, spending most of their adult life in freshwater, then returning to the sea only to reproduce. They form extensive burrows in the riverbanks and levees, thus posing a direct threat to earthen water control structures. Further information on the life history of mitten crabs can be found in Veldhuizen and Stanish (2002), an ASN fact sheet ([http://el.erc.usace.army.mil/ansrp/eriocheir\\_sinensis.htm](http://el.erc.usace.army.mil/ansrp/eriocheir_sinensis.htm)), and in Ray (2005).

The Asian date mussel, native to intertidal and subtidal sediments from Siberia to the Red Sea, is now found in Australia, New Zealand, the eastern Mediterranean, and southern France (Crooks 1996). It was probably introduced into the state of Washington during introduction of oysters in 1924 and has since spread to Southern California. It produces planktonic larvae that can remain in the water column as long as 55 days, then settle onto muddy or sandy substrates. It forms dense beds that alter both sediment composition and native benthic assemblages (Crooks 1998, Crooks and Khim 1999). Success of seagrass restoration projects can be compromised in heavily infested areas (Reutsch and Williams 1998). Additional information on this species can be found in Ray (2005).

**Nuclear worm:** One species, not listed as an NIS, but recently offered by some live bait dealers in the Chesapeake Bay area, is the so-called "nuclear worm." A very large, bright pink polychaete reaching lengths of 2 m, it is a native of Viet Nam (Ward 2002). Although often referred to as *Namalycastis abiuma*, a recent taxonomic revision indicates that neither this species nor any of its



variants reach lengths more than 1 in. (Glasby 1999). It seems highly likely that this animal represents an undescribed species. It is probably not a threat as an introduced species because it cannot survive temperatures below 20 °C (68 °F) (Ward 2002).

**ACKNOWLEDGEMENTS:** This review was sponsored by the U. S. Army Engineer Research and Development Center, Vicksburg, MS, under the Aquatic Nuisance Species Research (ANSRP) Program.

**POINTS OF CONTACT:** For additional information, contact Dr. Gary L. Ray (601-634-2589, [Gary.Ray@erdc.usace.army.mil](mailto:Gary.Ray@erdc.usace.army.mil)) or the Program Manager of the Aquatic Nuisance Species Research (ANSRP) Program, Mr. Glenn Rhett (601-634-3717), [Glenn.G.Rhett@erdc.usace.army.mil](mailto:Glenn.G.Rhett@erdc.usace.army.mil). This technical note should be cited as follows:

Ray, G. L. (2005). "Invasive estuarine and marine animals of the South Atlantic and Puerto Rico," ANSRP Technical Notes Collection (ERDC TN-ANSRP-05-5), U.S. Army Engineer Research and Development Center, Vicksburg, MS.  
<http://el.erdc.usace.army.mil/ansrp>

## REFERENCES

- Benson, A. J., Fuller, P. L., and Jacono, C. C. (2001). "Summary report of nonindigenous aquatic species in U.S. Fish and Wildlife Service Region 4," United States Geological Survey, Florida Caribbean Science Center. Available online at [http://cars.er.usgs.gov/Region\\_4\\_Report/R4finalreport.pdf](http://cars.er.usgs.gov/Region_4_Report/R4finalreport.pdf).
- Bourdeau, P. E., and O'Connor, N. J. (1999). "Prey preferences of the recently-introduced Western Pacific shore crab, *Hemigrapsus sanguineus*, feeding on molluscs and macroalgae in southeastern Massachusetts." *First National Conference on Marine Bioinvasions*. Cambridge, MA. January 24-27, 1999. Available online at <http://massbay.mit.edu/exoticspecies/conferences/1999>.
- Buddo, D., Steele, R. D., and D'Oyen, E. R. (2003). "Distribution of the invasive indo-pacific Green Mussel, *Perna viridis*, in Kingston Harbour, Jamaica," *Bulletin of Marine Science* 73, 433-441.
- Carlton, J. T. (1985). "Transoceanic and intraoceanic dispersal of coastal marine organisms: The biology of ballast water," *Oceanography and Marine Biology: An Annual Review* 23, 313-374.
- Carlton, J. T. (2001). *Introduced Species in U.S. Coastal Waters: Environmental Impacts and Management Priorities*. Pew Oceans Commission, Arlington, VA. Available at [http://www.pewtrusts.org/pdf/env\\_oceans\\_species.pdf](http://www.pewtrusts.org/pdf/env_oceans_species.pdf).
- Carlton, J. T., and Hodder, J. (1995). "Biogeography and dispersal of coastal marine organisms: Experimental studies on a replica of a 16<sup>th</sup> century sailing vessel," *Marine Biology* 121, 721-730.
- Carlton, J. T., and Ruckelshaus, M. H. (1997). "Nonindigenous marine invertebrates and algae." *Strangers in Paradise. Impact and Management of Nonindigenous Species in Florida*. D. Simberloff, C. Schmitz, and T. C. Brown, ed., Island Press, Washington, DC, 187-201.
- Carlton, J. T., Reid, D. M., and van Leeuwen, H. (1995). "Shipping Study. The role of shipping in the introduction of nonindigenous aquatic organisms to the coastal waters of the United States (other than the Great Lakes) and an analysis of control options," The National Sea Grant College Program/Connecticut Sea Grant Project R/ES-6, Report No. CG-D-11-95.

- Clark, P. F., Rainbow, P. S., Robbins, R. S., Smith, B., Yeomans, W. E., Thomas, M., and Dobson, A. G. (1998). "The alien Chinese Mitten Crab, *Eriocheir sinensis* (Crustacea: Decapoda: Brachyura), in the Thames catchment," *Journal of the Marine Biological Association of the United Kingdom* 78, 1215-1221
- Cohen, A. N., and Carlton, J. T. (1995). "Biological Study. Nonindigenous aquatic species in a United States estuary: A case study of the biological invasions of the San Francisco Bay and Delta," a report for the United States Fish and Wildlife Service, Washington, DC, and the National Sea Grant Program, Connecticut Sea Grant Publication PB96-166525. Available online at <http://www.anstaskforce.gov/sfinvade.htm>.
- Crooks, J. A. (1996). "The population ecology of an exotic mussel, *Musculista senhousia*, in a Southern California bay," *Estuaries* 19, 42-50.
- Crooks, J. A. (1998). "Habitat alteration and community-level effects of an exotic mussel, *Musculista senhousia*," *Marine Ecology Progress Series* 162, 137-152.
- Crooks, J. A., and Khim, H. S. (1999). "Architectural vs. biological effects of a habitat-altering, exotic mussel, *Musculista senhousia*," *Journal of Experimental Marine Biology and Ecology* 240, 53-75.
- Epifaunio, C. E., Dittel, A. I., Park, S., Schwalm, S., and Fouts, A. (1998). "Early life history of *Hemigrapsus sanguineus*, a non-indigenous crab in the Middle Atlantic Bight (USA)," *Marine Ecology Progress Series* 170, 231-238.
- Erlich, P. R. (1989). "Attributes of Invaders and the invading processes: Vertebrates." *Biological Invasions: A Global Perspective*. J. A. Drake et al., ed., 1989 SCOPE. John Wiley and Sons, Ltd, 315-328. Available online at <http://www.icsu-scope.org/downloadpubs/scope37/scope37.html>.
- Federal Register. (1999). Executive Order 13112 of February 3, 1999—Invasive Species. Federal Register 64, No. 25. Available online at <http://www.invasivespecies.gov/laws>.
- Fuller, P. (2005). *Sphaeroma walkeri*. Nonindigenous Aquatic Species Database, Gainesville, FL. Available online at <http://nas.er.usgs.gov/queries/factsheet.asp?SpeciesID=1084>.
- Glasby, C. J. (1999). "The Namanereidinae (Polychaeta: Nereididae). Part I. Taxonomy and Phylogeny," *Records of the Australian Museum* 25, 1-129.
- Gulf States Marine Commission. (2003). "Non-Native Aquatic Species in the Gulf of Mexico and South Atlantic Regions." Available online at <http://nis.gsmfc.org/>.
- Hare, J. A., and Whitfield, P. E. (2003). *An integrated assessment of the introduction of Lionfish (Pterois volitans/miles complex) to the Western Atlantic Ocean*. National Atmospheric and Oceanographic Administration, National Ocean Service Technical Memorandum CCFHR 1.
- Hartman, M. J., Stancyk, S E., and Lohrer, A. M. (2001). "An invasive crab, *Petrolisthes armatus*, as alternative prey in an oyster reef ecosystem." *16<sup>th</sup> Biennial Conference of the Estuarine Research Federation*, November 4-8, 2001. St. Petersburg Beach, FL. Available online at <http://erf.org/erf2001>.
- Hicks, D. W., and Tunnell, J. W., Jr. (1993). "Invasion of the south Texas coast by the edible brown mussel *Perna perna* (Linnaeus, 1758)," *Veliger* 36, 92-94.
- Hicks, D. W., and Tunnell, J. W., Jr. (1995). "Ecological notes and patterns of dispersal in the recently introduced mussel, *Perna perna* (Linne 1758), in the Gulf of Mexico," *American Malacological Bulletin* 11, 203-206.
- Hicks, D. W., Tunnell, J. W., Jr., and McMahon, R. F. (2001). "Population dynamics of the nonindigenous brown mussel *Perna perna* in the Gulf of Mexico compared to other worldwide populations," *Marine Ecology Progress Series* 211, 181-192.

- Highley, T. L. (1999). "Biodeterioration of wood." *Wood handbook--Wood as an engineering material*. Gen. Tech. Rep. FPL-GTR-113, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI. Available online at <http://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr113/ch13.pdf>.
- Hoagland, K. E. (1983). *Life history characteristics and physiological tolerances of Teredo bartschi, a shipworm introduced into two temperate zone nuclear power plant effluents*. Hemisphere Publishing Co., Miami Beach, FL, 609-622.
- Hollebone, A. L., and Hay, M. E. (2003). "An invasive crab in the South Atlantic Bight; friend or foe?" *Third International Conference on Bioinvasions*. March 16-19, 2003, La Jolla, CA. Available online at <http://massbay.mit.edu/exoticspecies/conferences/2003>.
- Jensen, G. C., McDonald, P. S., and Armstrong, D. A. (2002). "East meets west: Competitive interactions between green crab *Carcinus maenas*, and native and introduced shore crab *Hemigrapsus* sp." *Marine Ecology Progress Series* 225, 251-262.
- Lavoie, D. M., Smith, L. D., and Ruiz, G. M. (1999). "The potential for intracoastal transfer of nonindigenous species in the ballast water of ships," *Estuarine, Coastal and Shelf Science* 48, 551-654.
- Lohrer, A. M. (2001). "The threat of invasion in South Carolina estuaries: A focus of exotic decapod crabs." *16<sup>th</sup> Biennial Conference of the Estuarine Research Federation*, November 4-8, 2001. St. Petersburg Beach, FL. Available online at <http://www.erf.org/erf2001/>.
- Lohrer, A. M., and Whitlatch, R. B. (1997). "Ecological studies on the recently introduced Japanese Shore Crab (*Hemigrapsus sanguineus*), in Eastern Long Island Sound." *Proceedings of the 2<sup>nd</sup> Northeast Conference on Nonindigenous Aquatic Nuisance Species*. Connecticut Sea Grant Publication CTSG-97-02, 49-60.
- Mann, R., and Harding, J. M. (2000). "Invasion of the North American Atlantic Coast by a large predatory Asian mollusk," *Biological Invasions* 2, 7-22.
- Mann, R., and Harding, J. M. (2003). "Salinity tolerance of larval *Rapana venosa*: implications for dispersal and establishment of an invading predatory gastropod on the North American Atlantic coast," *Biological Bulletin* 204, 96-103.
- McDermott, J. J. (1991). "A breeding population of the Western Pacific crab *Hemigrapsus sanguineus* (Crustacea: Decapoda: Grapsidae) established on the Atlantic coast of North America," *Biological Bulletin* 181, 195-198.
- Nature Conservancy. (2004). Website. <http://nature.org/wherewework/northamerica/states/northcarolina/initiatives/>.
- Padilla, D. K., and Williams, S. L. (2004). "Beyond ballast water: aquarium and ornamental trades as sources of invasive species in aquatic ecosystems," *Frontiers in Ecology and the Environment* 3, 131-138.
- Percival, S. R., and Wilson, K. (2001). "Feeding and substrate preferences of the Japanese shore crab, *Hemigrapsus sanguineus*." *Second International Conference on Marine Bioinvasions*. New Orleans, LA. April 9-11, 2001. Available online at <http://massbay.mit.edu/exoticspecies/conferences/2001/>.
- Ray, G. L. (2005) "Invasive animal species in marine and estuarine environments: Biology and ecology." Technical Report ERDC/EL TR-05-2, U.S. Army Engineer Research and Development Center, Vicksburg, MS.
- Rehm, A. and Humm, H. J. (1973). "*Sphaeroma terebrans*: A threat to the mangroves of Southwestern Florida," *Science* 182, 173-174.
- Reutsch, T. B. H., and Williams, S. L. (1998). "Variable response of native eelgrass *Zostera marina* to a nonindigenous bivalve *Musculista senhousia*," *Oecologia* 113, 428-441.

- Ruiz, G. M., Fofonoff, P., Carlton, J. T., Wonham, M. J., and Hines, A. H. (2000). "Invasion of coastal marine communities in North America: Apparent patterns, processes, and biases," *Annual Review in Ecology and Systematics* 2000, 481-531.
- Torchin, M. E., Lafferty, K. D., Dobson, A. P., McKensie, V. J., and Kuris, A. M. (2003). "Introduced species and their missing parasites," *Nature* 421, 628-630.
- U.S. Environmental Protection Agency. (2000). "An initial survey of aquatic invasive species issues in the Gulf of Mexico region." Invasive Species Focus Team, Gulf of Mexico Program. EPA 855-R-00-003. Available online at <http://nis.gsmfc.org/>.
- U.S. Geological Survey. (2003). "South Florida Restoration Science Forum Website," available online at <http://sofia.usgs.gov/sfrsf/rooms/species/invasive/intro/>.
- U.S. Geological Survey. (2005). "Nonindigenous Aquatic Species Database," Gainesville, FL. <http://nas.er.usgs.gov>
- University of Georgia. (2002). "Invasive and other exotic species of North America," available online at <http://www.invasive.org/>.
- Veldhuizen, T., and Stanish, S. (2002). "Overview of the life history, distribution, abundance, and impacts of Chinese mitten crab *Eriocheir sinensis*." Appendix A, *A Draft National Management Plan for the Genus Eriocheir*. Aquatic Nuisance Species Task Force. February 2002. 37-5. Available online at <http://www.anstaskforce.gov/>.
- Ward, L. (2002). "More on *Namalycastis*" Annelida List Server Archives, August 5, 2002. Available online at <http://www.bio.net/hypermail/annelida/2002-August/002012.html>.
- Weigle, S. M., Smith, L. D., Carlton, J. T., and Pederson, J. (2005). "Assessing the risk of introducing exotic species via the live marine species trade," *Conservation Biology* 19, 213-223.
- Williams, J. D., and Meffe, G. K. (1999). "Nonindigenous species." *Status and trends of the nation's biological resources*. U.S. Geological Survey. Available online at <http://biology.usgs.gov/s+t/SNT/index.htm>.
- Wolfe, L. M. (2002). "Why alien invaders succeed: Support for the escape-from-enemy hypothesis," *American Naturalist* 160, 705-711.

**NOTE:** The contents of this technical note are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such products.

## APPENDIX A: NIS LISTINGS BY STATE FOR THE SOUTH ATLANTIC REGION AND PUERTO RICO

Species	Group	VA	NC	SC	GA	FL	PR
<i>Perkinsis marinus</i>	Protozoa	VA	NC	SC	GA	FL	
<i>Haplosporidium nelsoni</i>	Protozoa	VA					
<i>Nematostella vectensis</i>	Anthozoa	VA					
<i>Diadumene lineata</i>	Anthozoa	VA				FL	
<i>Haliplanella lineata</i>	Anthozoa					FL	
<i>Blackfordia virginica</i>	Hydrozoa	VA					
<i>Maeotias inexpectata</i>	Hydrozoa	VA		SC			
<i>Maeotias marginata</i>	Hydrozoa	VA					
<i>Phyllorhiza punctata</i>	Scyphozoa					FL	PR
<i>Tubificoides heterochaetus</i>	Oligochaete	VA					
<i>Boccardiella ligérica</i>	Polychaete	VA				FL	
<i>Demonax flecatus</i>	Polychaete	VA					
<i>Demonax</i> sp.	Polychaete	VA					
<i>Ficopomatomus enigmaticus</i>	Polychaete	VA					
<i>Hydroides elegans</i>	Polychaete					FL	
<i>Namanereis littoralis</i>	Polychaete	VA					
<i>Polydora cornuta</i>	Polychaete					FL	
<i>Crassostrea ariakensis</i>	Bivalve	VA					
<i>Crassostrea gigas</i>	Bivalve	VA					
<i>Cyrenoida floridana</i>	Bivalve	VA					
<i>Ischadium recurvum</i>	Bivalve	VA					
<i>Lyrodus medilobatus</i>	Bivalve					FL	
<i>Mytella charruana</i>	Bivalve					FL	
<i>Perna viridis</i>	Bivalve				GA	FL	
<i>Pinctada margaritifera</i>	Bivalve					FL	
<i>Rangia cuneata</i>	Bivalve	VA	NC			FL	
<i>Tridacna crocera</i>	Bivalve					FL	
<i>Tridacna maxima</i>	Bivalve					FL	
<i>Teredo bartschi</i>	Bivalve	VA					
<i>Teredo furcifera</i>	Bivalve	VA					
<i>Teredo navalis</i>	Bivalve	VA					
<i>Assiminea succinea</i>	Gastropod	VA					
<i>Eupleura sulcidentata</i>	Gastropod	VA					
<i>Littorina littorea</i>	Gastropod	VA				FL	
<i>Melampus floridanus</i>	Gastropod	VA					
<i>Melanoides tuberculatus</i>	Gastropod					FL	
<i>Myostella myosotis</i>	Gastropod	VA				FL	
<i>Rapana venosa</i>	Gastropod	VA					
<i>Stramonita haemastoma</i>	Gastropod	VA					
<i>Truncatella subcylindrica</i>	Gastropod					FL	
<i>Vitrinella floridana</i>	Gastropod	VA					

(Sheet 1 of 3)



Species	Group	VA	NC	SC	GA	FL	PR
<i>Cuthona oerca</i>	Nudibranch					FL	
<i>Ercolania fuscovittata</i>	Nudibranch					FL	
<i>Placida dendritica</i>	Nudibranch	VA					
<i>Tenellia adspersa</i>	Nudibranch	VA					
<i>Argulus japonicus</i>	Copepod	VA				FL	
<i>Eurytemora affinis</i>	Copepod	VA	NC	SC			
<i>Balanus amphitrite</i>	Barnacle	VA	NC	SC		FL	
<i>Balanus reticularis</i>	Barnacle					FL	
<i>Balanus trigonus</i>	Barnacle					FL	
<i>Loxothylacus panopaei</i>	Barnacle	VA					
<i>Amphilocheus</i> sp.	Amphipod	VA					
<i>Apocorophium acutum</i>	Amphipod	VA					
<i>Chelura terebrans</i>	Amphipod					FL	
<i>Monocorophium acheruscium</i>	Amphipod	VA					
<i>Monocorophium insidiosum</i>	Amphipod	VA					
<i>Gitanopsis</i> sp.	Amphipod	VA					
<i>Stenothoe gallensis</i>	Amphipod	VA					
<i>Ligia exotica</i>	Isopod	VA	NC	SC		FL	
<i>Sphaeroma terebrans</i>	Isopod	VA				FL	
<i>Sphaeroma walkeri</i>	Isopod					FL	
<i>Synidotea laevaidorsalis</i>	Isopod			SC			
<i>Zeuxo maledivensis</i>	Tanaid					FL	
<i>Americamysis almyra</i>	Mysid	VA					
<i>Callinectes bocourti</i>	Crab		NC	SC		FL	
<i>Callinectes exasperatus</i>	Crab				GA		
<i>Carcinus maenas</i>	Crab	VA					
<i>Charybdis helleri</i>	Crab					FL	
<i>Hemigrapsus sanguineus</i>	Crab	VA	NC				
<i>Petrolisthes armatus</i>	Crab			SC	GA	FL	
<i>Platychirograpsus spectabilis</i>	Crab					FL	
<i>Scylla serrata</i>	Crab					FL	
<i>Macrobrachium olfersi</i>	Shrimp					FL	
<i>Penaeus monodon</i>	Shrimp			SC	GA	FL	
<i>Penaeus stylirostris</i>	Shrimp			SC		FL	
<i>Penaeus vannanmei</i>	Shrimp			SC		FL	
<i>Placopsidella grandis</i>	Insect	VA					
<i>Anisobasis maritima</i>	Insect	VA					
<i>Bugula neritina</i>	Bryozoan	VA					
<i>Sunanella sbogae</i>	Bryozoan					FL	
<i>Victorella pavidula</i>	Bryozoan					FL	
<i>Barentsia benedini</i>	Ectoproct	VA					
<i>Loxosomatoides laevis</i>	Ectoproct	VA					
<i>Ascidella aspersa</i>	Tunicate	VA					
<i>Botrylloides violaceus</i>	Tunicate	VA					
<i>Botryllus schosseri</i>	Tunicate	VA				FL	

(Sheet 2 of 3)

Species	Group	VA	NC	SC	GA	FL	PR
<i>Diplosoma listerianum</i>	Tunicate	VA					
<i>Ecteinascidia turniata</i>	Tunicate	VA					
<i>Mogula manhatetensis</i>	Tunicate	VA					
<i>Styela clavata</i>	Tunicate	VA					
<i>Styela canopus</i>	Tunicate	VA					
<i>Styela plicata</i>	Tunicate	VA				FL	
<i>Alosa aestivalis</i>	Fish	VA	NC		GA		
<i>Alosa pseudoharengus</i>	Fish	VA			GA		
<i>Alosa sapidissima</i>	Fish	VA			GA	FL	
<i>Anguilla rostrata</i>	Fish		NC				
<i>Cromileptes altivelis</i>	Fish					FL	
<i>Dorosoma cepedianum</i>	Fish	VA			GA		
<i>Dorosoma petenense</i>	Fish	VA			GA	FL	
<i>Gadus morhua</i>	Fish	VA					PR
<i>Monopterus albus</i>	Fish				GA	FL	
<i>Morone saxatilis</i>	Fish	VA		SC	GA	FL	
<i>Oncorhynchus kisutch</i>	Fish	VA					
<i>Oncorhynchus nerka nerka</i>	Fish		NC				
<i>Oncorhynchus tshawytscha</i>	Fish	VA					
<i>Pomacanthus annularis</i>	Fish					FL	
<i>Pomacanthus asfur</i>	Fish					FL	
<i>Pomacanthus imperator</i>	Fish					FL	
<i>Pomacanthus maculosus</i>	Fish					FL	
<i>Pomacanthus semicircularis</i>	Fish					FL	
<i>Pomacanthus xanthometopon</i>	Fish					FL	
<i>Pterois volitans</i>	Fish		NC		GA	FL	
<i>Rhinecanthus verrucosus</i>	Fish					FL	
<i>Salmo salar</i>	Fish	VA	NC	SC			
<i>Scatophagus argus</i>	Fish					FL	
<i>Zebrasoma desjardinii</i>	Fish					FL	
<i>Zebrasoma flavescens</i>	Fish					FL	
<i>Zebrasoma veliferum</i>	Fish					FL	
<i>Zebrasoma xanthurum</i>	Fish					FL	
(Sheet 3 of 3)							